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On the Positive-Parity States with Anomalous α-Decay Properties in ^{12}C

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The excited positive-parity levels at 7.7 and 10.3 MeV in ^{12}C nucleus are famous for their anomalously large α-decay widths.[1)] They have been considered to be typical states with α-clustering, which is readily expected by Ikeda diagram,[2)] and investigated theoretically.[3)] But unfortunately experimental information is so rare that the spin of the 10.3 MeV level is not established as yet.[4)] On the standpoint of α-clustering expected, we have studied dynamical properties of 3 α-particle system microscopically by using the generator coordinate method (GCM). And we have obtained the excited positive-parity states, $0_2{}^+$, $2_2{}^+$, $0_3{}^+$, $2_3{}^+$, $4_2{}^+$ and $3_1{}^+$ (Ref. 5), hereafter referred to as I). The purpose of the present paper is to investigate α-decay properties of these states and to clarify nuclear structure of excited states in this energy region of ^{12}C.

In Fig. 1 an energy spectrum obtained by the GCM calculation I shows that the $2_2{}^+$ state is the next positive-parity state of the $0_2{}^+$ state. The $0_3{}^+$ state comes out about 4 MeV high above the $0_2{}^+$ state together with the degenerate $2_3{}^+$ state. This situation is not changed by any truncation of the basis wave functions for large inter-α-distances. Compared with experiment

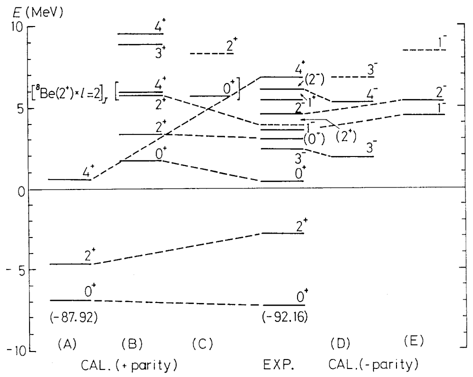

Fig. 1. Energy spectrum from I. Levels are classified into several bands. (B) and (C) show the excited positive-parity levels. See Ref. 5).

the energy difference between the $0_2{}^+$ and $2_2{}^+$ states is fairly good, if the $2_2{}^+$ state is assigned to the 10.3 MeV level. Then the 2^+ assignment is energetically favoured.

Further we analyse α-decay widths of these states by using so-called "Separation Energy Method",[6)] in which inner α-reduced width amplitudes $ry_{c\equiv(I,l)}(r)$ are smoothly connected to outer resonance tails $G_l(k_c r)$ with given separation energies. $\theta^2_{\alpha,c}$ and Γ_α are estimated by the relations $\theta^2_{\alpha,c}(a) = (a/3)\,(ay_c(a))^2$ and $\Gamma_\alpha = \sum_c \Gamma_{\alpha,c} = \sum_c 2P_c(a)\,(3\hbar^2/2\mu a^2)\,\theta^2_{\alpha,c}(a)$, where a is a channel radius and $P_c \equiv k_c a/(F_l{}^2(k_c a)+G_l{}^2(k_c a))$. In the calculation of the α-reduced width amplitudes, a Brink-Bloch type wave function ($d=3.5$ fm) is taken for the ^{8}Be core.

Calculated α-decay widths are listed in the Table, together with the existing experimental data. We can see that the width of the $0_2{}^+$ state is reproduced excellently well and that a calculated α-decay width of the $2_2{}^+$ state is fairly large. On the other hand, an α-decay width of the $0_3{}^+$ state is rather small and smaller than that of the $2_2{}^+$ state although it can decay into the ^{8}Be ground state with a partial angular momentum $\boldsymbol{l}=0$. Hence we suggest strongly that the 10.3 MeV broad level is the $2_2{}^+$

Table I. α-decay widths in eV for the 0_2^+ state and in keV for the others. Values in parenthesis are those when the renormalization correction is taking into account.[6] Calculated θ_α^2 value for the 0_2^+ state is 0.75 at 5.8 fm, whereas 0.82 in exp. The excitation energy of the 0_3^+ state (not observed yet) is assumed to be 11.7 MeV estimated by 7.7 MeV (0_2^+) + 4 MeV).

	0_2^+ (7.66 MeV)	2_2^+ (10.3)	0_3^+ (10.3)[a)]	0_3^+ (11.7)	2_3^+ (11.2)
$\Gamma_{\text{exp.}}$	8.7±2.7 (eV)	3000±700 keV			430±80
$\Gamma_{\text{cal.}}$ (a=5.8)	7.9 (14.)	1200 (2600)			
$\Gamma_{\text{cal.}}$ (a=6.6)	8.8 (11.)	1000 (1400)	380 (550)	710 (1000)	73 (87)
$\Gamma_{\text{cal.}}$ (a=7.4)			490 (560)	1000 (1200)	81 (85)

a) Calculated according to the assumption that the excitation energy is 10.3 MeV, which gives the wave number k_c in the penetration factor.

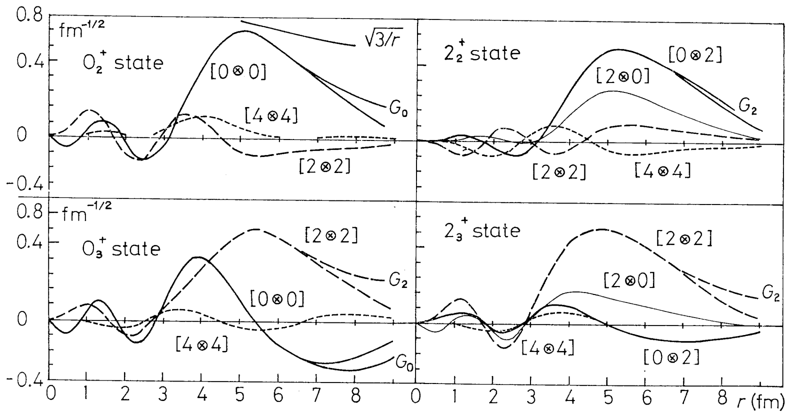

Fig. 2. α-reduced width amplitudes $r\mathcal{Y}_c(r)$ and connected resonance tails $G_l(r)$. Brackets $C \equiv [I \times l]$ denote a spin of ^{8}Be core I and an orbital angular momentum of α-particle l, identifying channels. Wave functions are normalized in whole space in bound state approximation.

state. The unexpected narrowness of the α-decay width of the 0_3^+ state in spite of its rather high excitation energy is easily understood by inspecting the α-reduced width amplitudes. We can see in Fig. 2 that the states have distinct α-clusterings. Their amplitudes, however, concentrate on proper channels respectively. Then we can classify the states into two groups; one includes the 0_2^+ and 2_2^+ states, the other does the 0_3^+ and 2_3^+ states. In the former an α-particle interacts mainly with the ^{8}Be ground state, while in the latter it interacts with the first excited state of ^{8}Be. Then we have a weak coupling picture of the rotational motion of ^{8}Be core and an α-particle motion. It is worthwhile noticing here that from this analysis we can recognize that positive parity excited states with distinct α-clustering are exhausted in this energy region by the states obtained. In decays of dominant components into respective members of the rotational band of ^{8}Be, the widths show different tendencies between two groups due to different relative energy positions to the tops of the effective barriers. More precisely, in the 0_2^+ and 2_2^+ states, outward extensions of the tail parts due to the α-clusterings and increasing amplitudes in decaying channels cause the large α-decay widths. On the other hand, the latter states can hardly decay into their proper channel where they have their dominant components. Thus their total α-decay widths mainly depend on the small components involved which decay into the ^{8}Be ground state, and result in being rather narrow.

It is concluded that we have had a simple overview on the nuclear structure of the excited positive-parity states with distinct α-clustering and is strongly suggested that a spin of the broad 10.3 MeV level is to be 2^+ with the dominant $[^8\mathrm{Be}(0^+)\otimes \boldsymbol{l}=2]_{J=2}$ component. As for the somewhat smaller prediction of its total width, it is worth-while mentioning a possibility that the broad $0_3{}^+$ and $2_3{}^+$ states at somewhat higher excitation energies may contribute to the extremely large width observed, overlapping with the $2_2{}^+$ state.

1) F. Ajzenberg-Selove, Nucl. Phys. **A248** (1975), 1.
2) K. Ikeda, N. Takigawa and H. Horiuchi, Prog. Theor. Phys. Suppl. Extra Number (1968), 464.
3) H. Horiuchi, K. Ikeda and Y. Suzuki, Prog. Theor. Phys. Suppl. No. 52 (1972), 89.
4) H. Morinaga, Phys. Letters **21** (1966), 98.
5) E. Uegaki, S. Okabe, Y. Abe and H. Tanaka, Prog. Theor. Phys. **57** (1977), 1262.
6) M. Kawai and K. Yazaki, Prog. Theor. Phys. **38** (1967), 850.
H. Horiuchi and Y. Suzuki, Prog. Theor. Phys. **49** (1973), 1974.

Note Added: Recently Y. Fukushima and M. Kamimura also have studied the structure of ^{12}C nuclei by the Resonating Group Method (to be published in *the Proceedings of the International Conference on Nuclear Structure, Tokyo, 1977*).